United States Brazil Canada Finland France Japan Netherlands United Kingdom

International Earth Observing Constellation Mission Operations Working Group

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Active Constellation Neighbor Analysis

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Overview

- ***Introduction, Inputs and Assumptions***
  - What satellites were considered for this analysis and why?
- ***3D visualizations of active satellites referenced to the Morning and Afternoon constellations***
- ***High level close approach analysis***
  - Includes only active satellites traversing the constellation envelope
- ***Conclusions***
- ***Backup slides***
  - 3D visualizations by country of origin
  - Satellite table of properties

Goal

Increase constellation situational awareness and safety by analyzing nearby active satellites

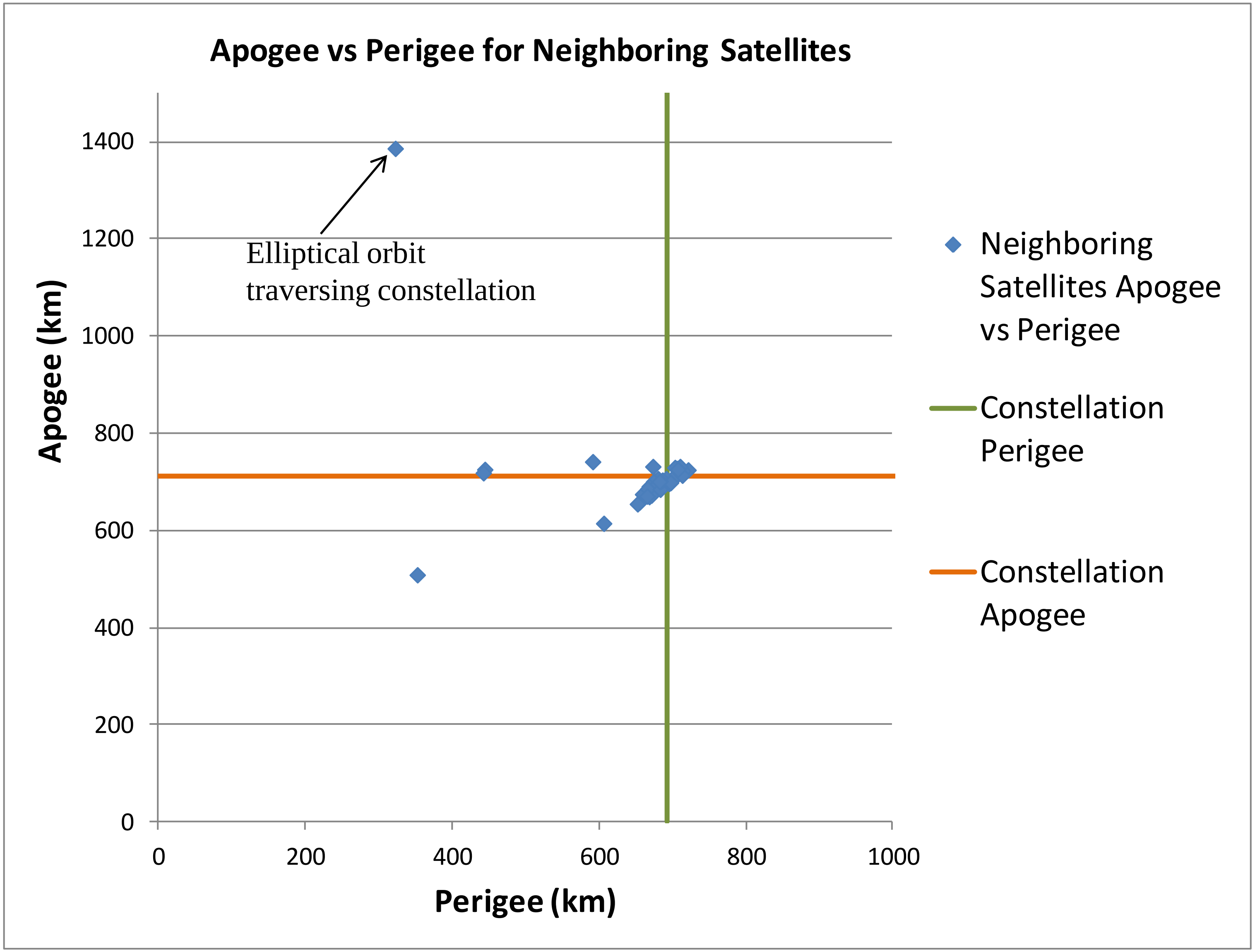
What Satellites Were Considered and Why

- ***Filtering objects near the constellation***
  - Used CARA MOWG Spring 2014 presentation of 705 km and 692 km neighbors and results from "Aerospace Corporation Debris Risk Study" large object analysis
  - CARA analysis considered satellites within +/- 25 km of the constellation's nominal apogee and perigee
- ***How can you determine a satellite's status?***
  - Use the internet to research the current status
    - It is not always straightforward to determine whether a satellite is still active
    - For this analysis, any satellite reported to be operational within the last two years was considered active
  - Propulsion/maneuverability was determined or inferred, if possible, but results not used in analysis
- ***Why only active satellites***
  - These are missions where it may be possible to contact an operator to coordinate during a close approach

Inputs and Assumptions

- ***Based on the criteria shown on the previous slide, 54 foreign satellite neighbors were identified***
  - 58 satellites were identified through research; however, four did not have TLEs available needed to complete this analysis
- ***Accessed satellite files from www.space-track.org***
  - Used NORAD TLE files from Mar 24 2015
- ***Aqua & Terra states taken from definitive ephemeris***
  - Aqua and Terra were used as proxies for the Afternoon and Morning Constellations, respectively.
- ***Orbit parameter data in the back-up slides is from space-trak.org***
- ***This data is informational only; no visualizations or orbit property data provided in this presentation should be used for conjunction analysis***

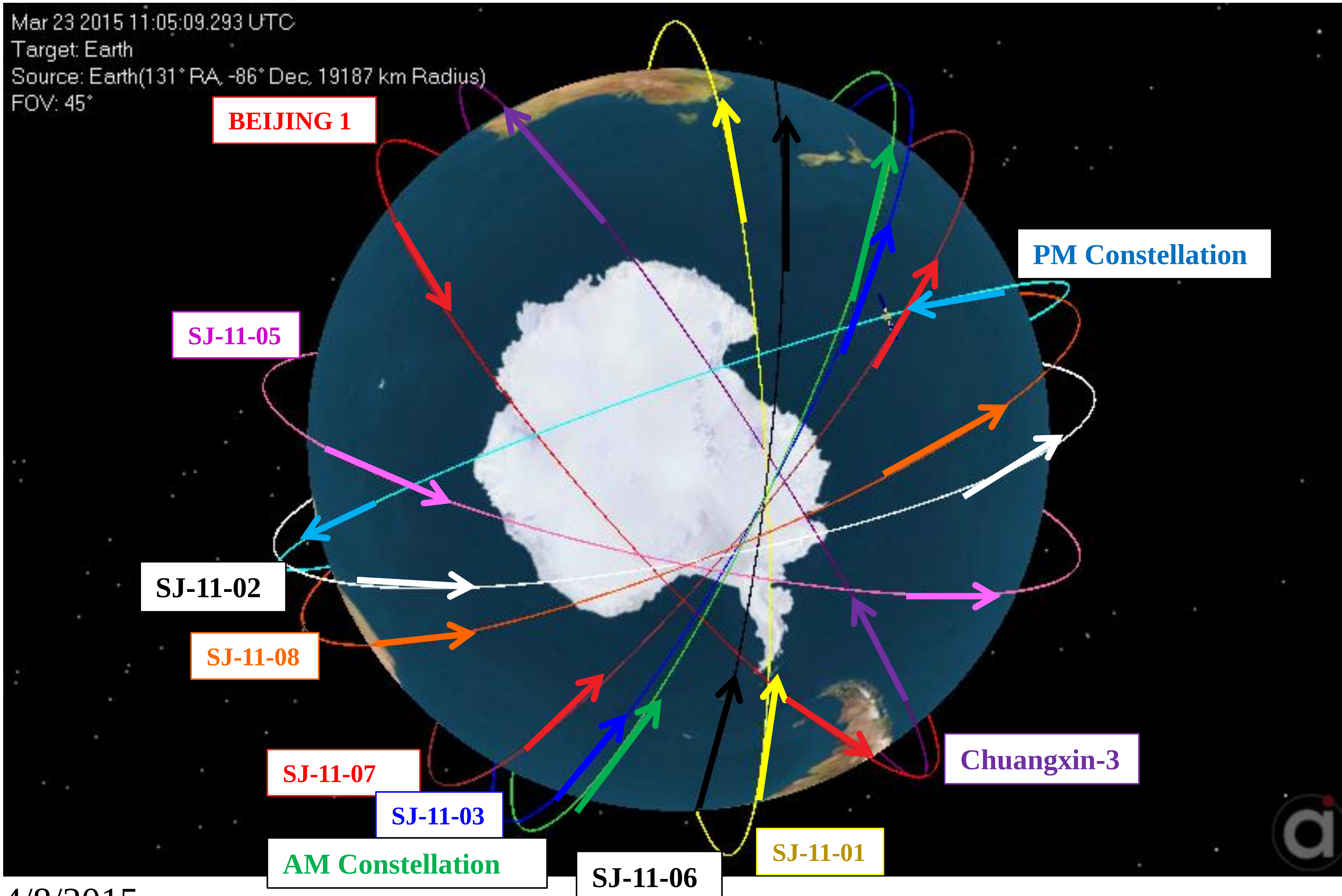
Neighboring Satellite Overview



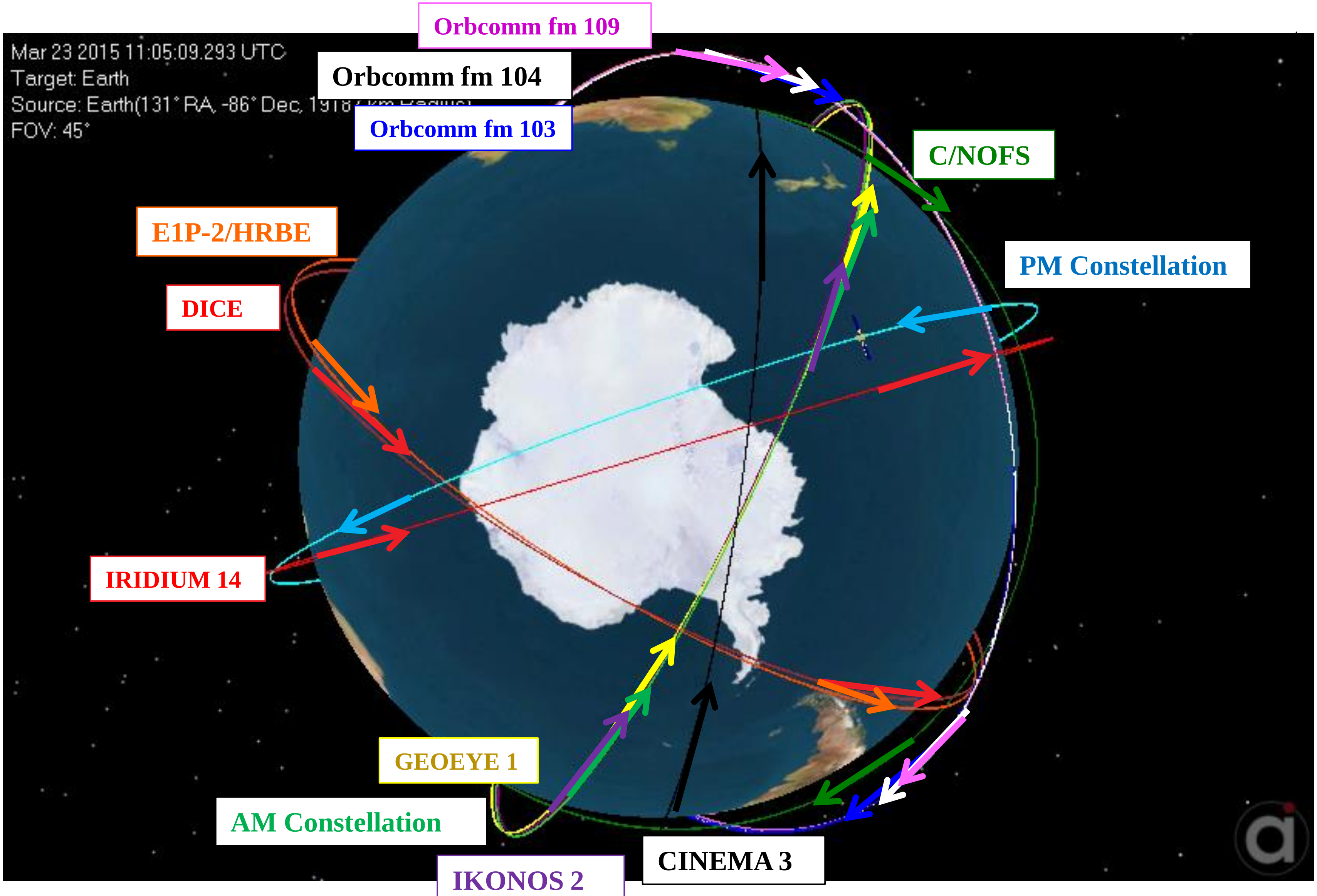
The majority of active constellation neighbors have apogee and perigee values similar to the morning and afternoon constellation.

Many fly in similar sun-synchronous orbits.

Chinese Satellite Orbits



US Satellite Orbits



CLOSE APPROACH ANALYSIS

Background

- ***27 foreign satellites were identified as active and potentially maneuverable***
  - All 54 satellites identified are actively monitored by the CARA team
- ***Historical data for each of these satellites was collected for high level assessment of close approaches to the morning and afternoon constellations***
- ***Aqua and Terra data were used as representative cases for the morning and afternoon constellations, respectively***
  - Analysis of each satellite versus each constellation member not manageable
  - conclusions drawn from Aqua/Terra are reasonable to infer for rest of constellation members
- ***Three month period of historical data was used***
  - All available NORAD TLE's were collected between Jan 01 2014 – Mar 30 2015
    - Maneuvers of satellite could not be determined accurately due to TLE noise
  - The set of TLE's were used to create ephemerides for each satellite

Analysis Methodology

- ***For each satellite:***
  - Calculate the mean SMA using the historical data
  - Determine the +/- 3-sigma SMA (high/low SMA)
  - Use the mean, high, and low values of the SMA and the 3 sigma max eccentricity to categorize each satellite as completely inside, completely outside, or traversing the constellation envelope
  - Use constellation envelope equation as described in the 2014 Constellation Operations Coordination Plan, details provided in back-up slides
  - Synodic period of each secondary with Aqua and Terra were examined for potentially traversing satellites
- ***High Level Results***
  - Satellites completely inside envelope = 0
  - Satellites completely outside of envelope = 7
  - Satellites traversing envelope = 20

Results

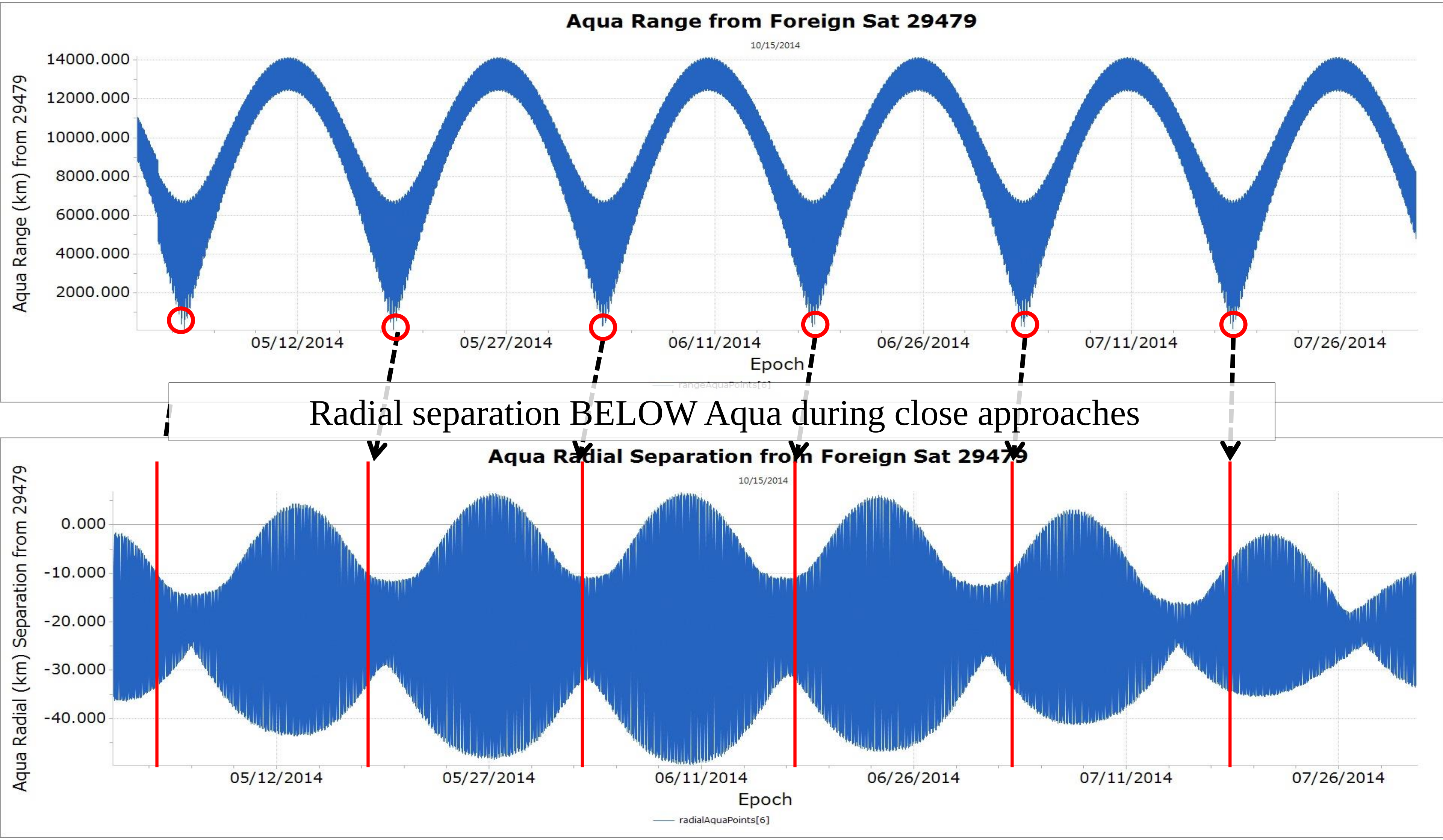
- ***The table below is a list of the 20 traversing foreign satellites that are active and their synodic period with Aqua and Terra.***

Foreign Sat ID	Aqua Synodic Period	Terra Synodic Period
36508 (CRYOSAT-2)	22 days	22 days
39030 (GOKTURK 2)	13 days	14 days
29479 (HINODE)	16 days	16 days
25777 (IRIDIUM 14)	50 days	40 days
35935 (ITUPSAT 1)	35 days	35 days
26268 (KOMPSAT 2)	20 days	20 days
38338 (KOMPSAT 3)	25 days	25 days
37789 (NIGERIASAT 2)	23 days	23 days
37790 (NIGERIASAT X)	150 days	100 days
38012 (PLEIADES 1)	80 days	75 days
39019 (PLEIADES 1B)	80 days	75 days
36037 (PROBA 2)	25 days	25 days
39634 (SENTINEL 1A)	25 days	25 days
36088 (SJ11-01)	35 days	35 days
37765 (SJ11-02)	35 days	35 days
37730 (SJ11-03)	35 days	40 days
39202 (SJ11-05)	45 days	45 days
39624 (SJ11-06)	50 days	50 days
38755 (SPOT 6)	50 days	70 days
35932 (SWISSCUBE)	40 days	40 days

Further Analysis

- ***Range and radial separation were examined and used to further narrow the group of traversing satellites***
- ***Some satellites may be traversing the constellation envelope, but are located below or above Aqua/Terra during the closest approaches.***
- ***Satellites located below Aqua/Terra are considered a lower risk:***
  - Posigrade maneuverability of Aqua/Terra allow for conjunction avoidance
  - If satellites in these orbits are no longer maneuvering or are maintaining their orbit, they will drop below or continue to stay below Aqua/Terra during the closest approaches
- ***The following slides show one of the traversing satellites which passes BELOW Aqua/Terra, and one which passes ABOVE or NEAR Aqua/Terra***
  - This is one example of the analysis which was performed for all satellites identified as traversing the constellation envelope

Aqua Range/Radial Plots from HINODE



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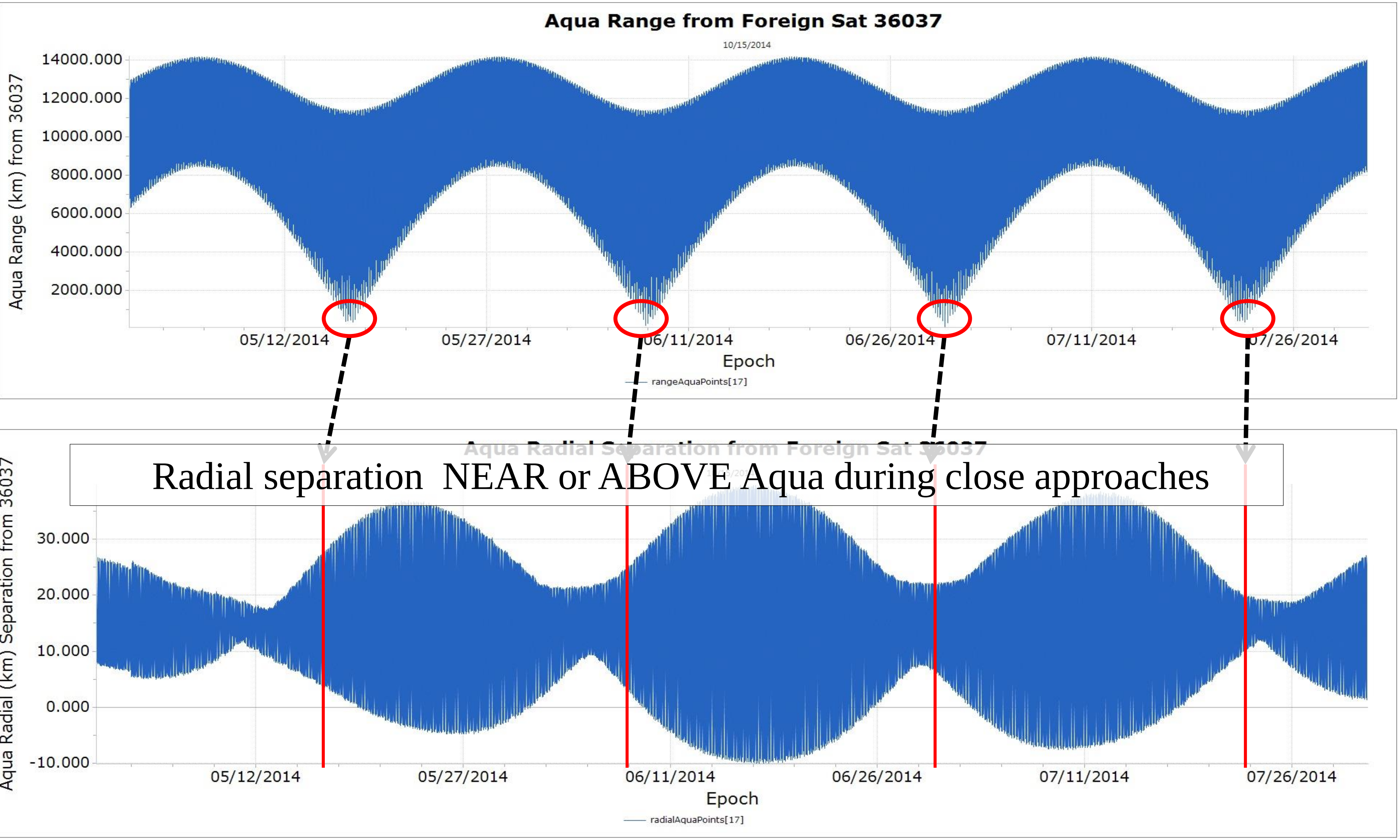
Aqua Range/Radial Plots from PROBA 2



Conclusions

- ***Based on this analysis:***
  - None of the 27 foreign satellites orbit **inside** of the constellation envelope
  - 7 of the 27 foreign satellites orbit **outside** of the constellation envelope
  - 20 of the 27 foreign satellites are traversing the constellation envelope
    - Of the 20 traversing, 5 are **nominally below** Aqua and Terra during close approach
    - Further analysis is necessary to ensure that these results are applicable to the rest of the constellation members
- ***15 traversing foreign satellites of interest based on analysis, which are listed on the next slide***
- ***This analysis is a 3 month snapshot of historical data. Due to unknown frequency of station keeping maneuvers and the inherent inaccuracy of TLE's, these results may not hold true for earlier or later periods of time.***
- ***CARA monitors all satellites and will provide assessments of future close approaches. The data collected in this analysis should be used for high level situational awareness only***

Final List of Traversing Foreign Satellites

Foreign Sat ID	Aqua Synodic Period	Terra Synodic Period
36508	22 days	22 days
39030	13 days	14 days
25777	50 days	40 days
35935	35 days	35 days
26268	20 days	20 days
37790	150 days	100 days
38012	80 days	75 days
39019	80 days	75 days
36037	25 days	25 days
36088 (SJ11-01)	35 days	35 days
37765 (SJ11-02)	35 days	35 days
39202 (SJ11-05)	45 days	45 days
39624 (SJ11-06)	50 days	50 days
38755	50 days	70 days
35932	40 days	40 days

**CARA monitors all satellites (including those listed in the table above) and will provide assessments of future close approaches. The data collected in this analysis should be used for high level situational awareness only.

Contact Information

- ***Questions or comments?***
  - esmo-eos-fds@lists.nasa.gov
  - FOC: (301)-614-5050

BACK UP SLIDES

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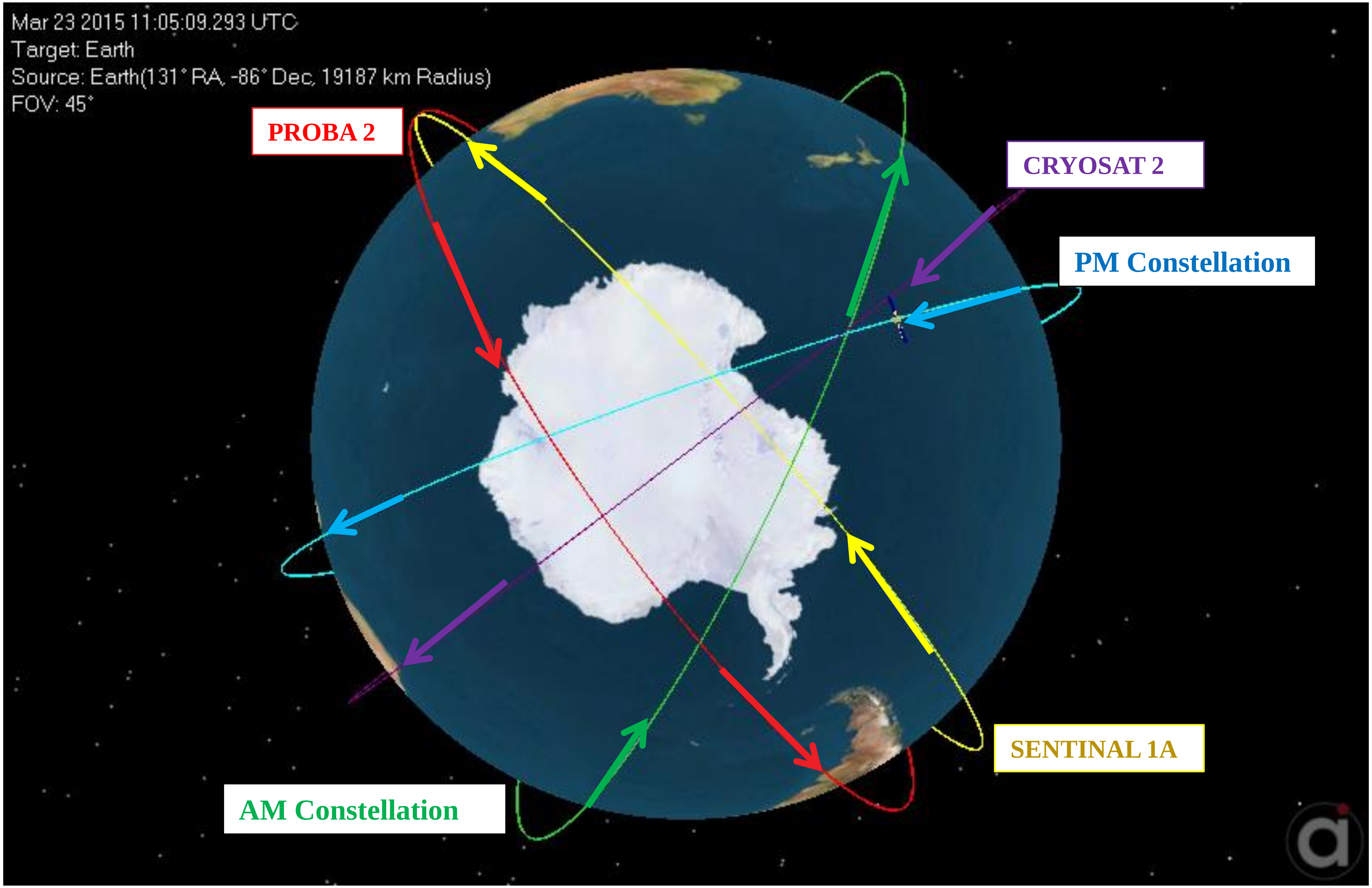
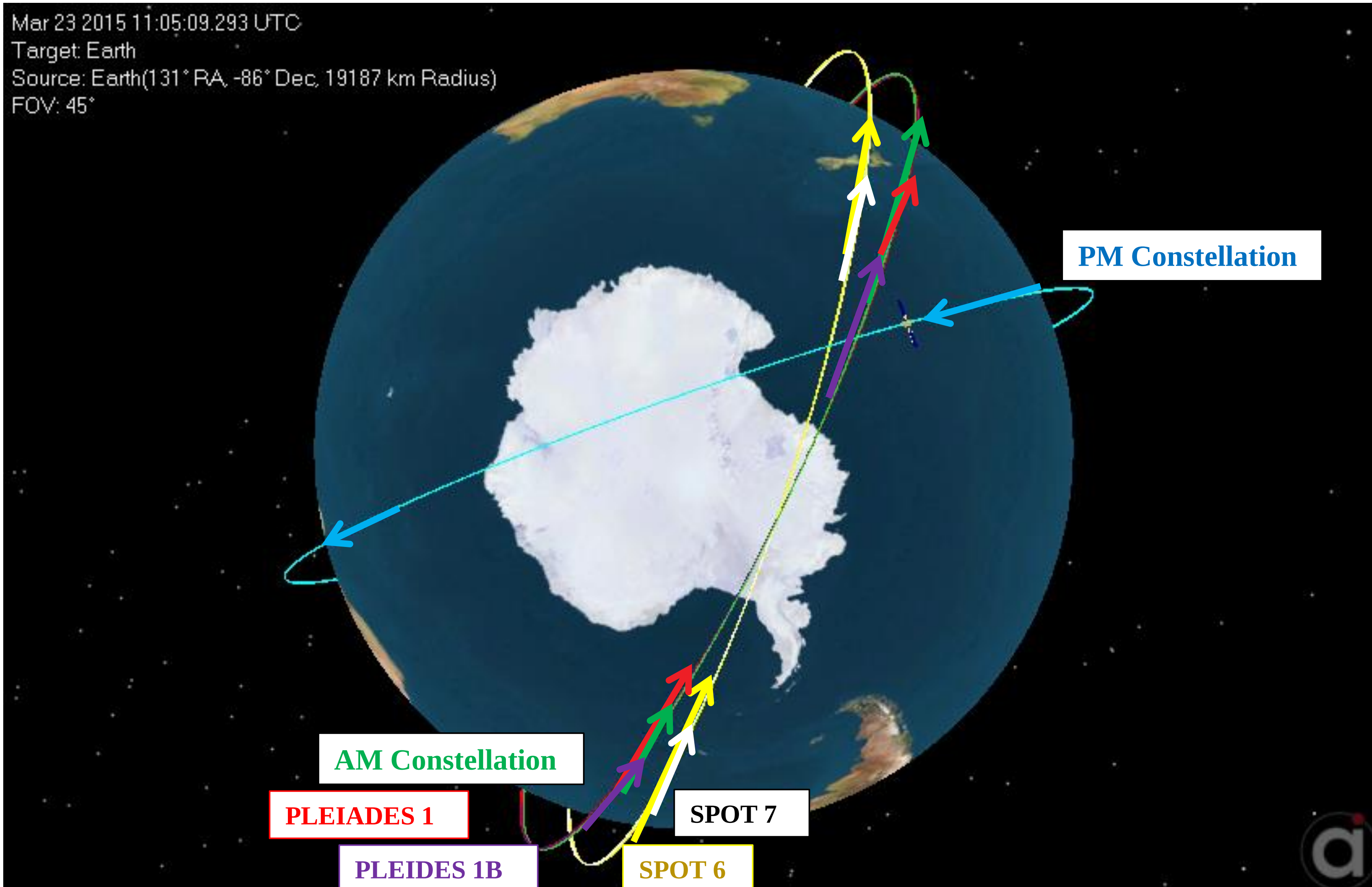
ESA Satellite Orbits



French Satellite Orbits



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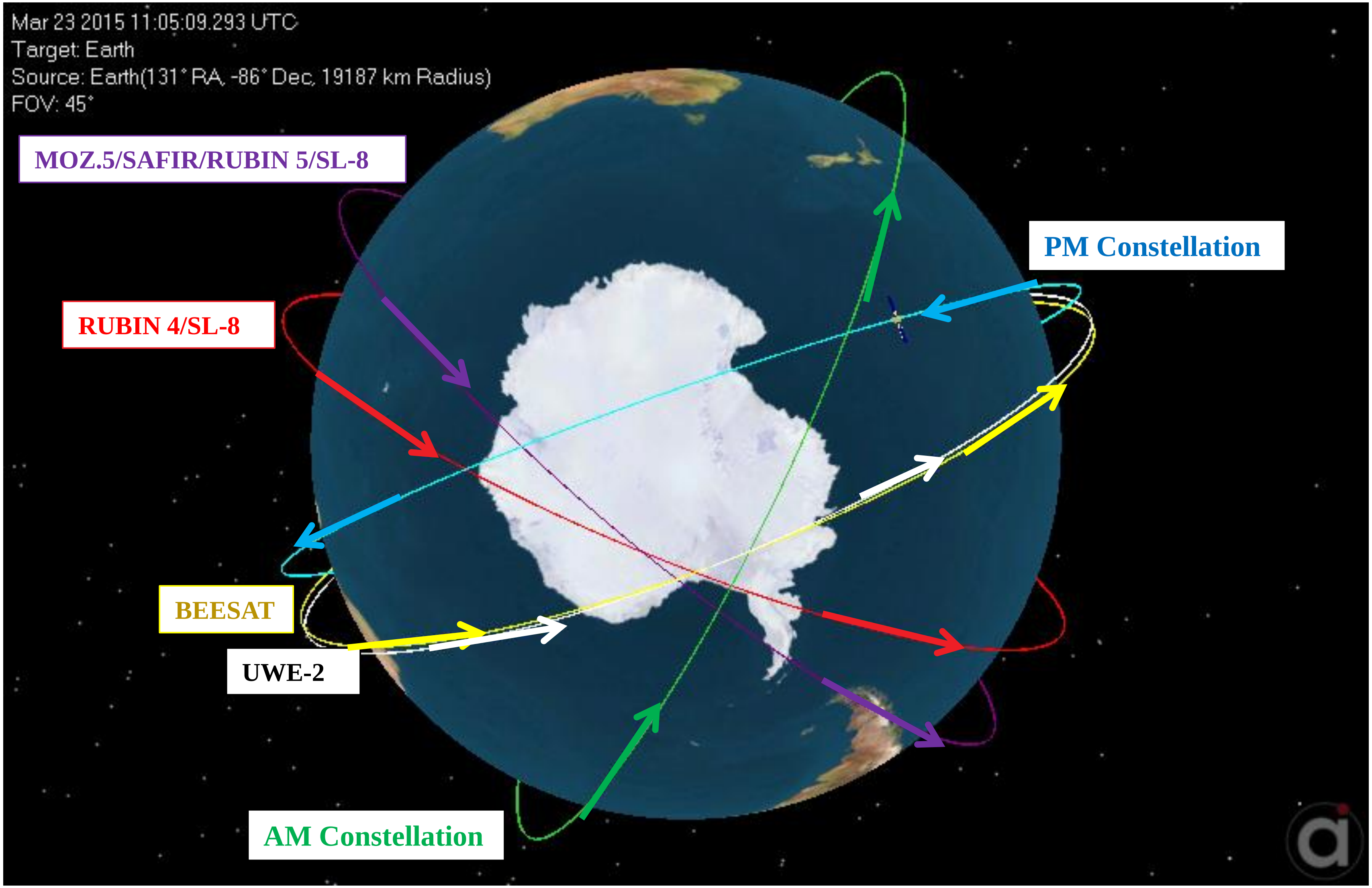
German Satellite Orbits



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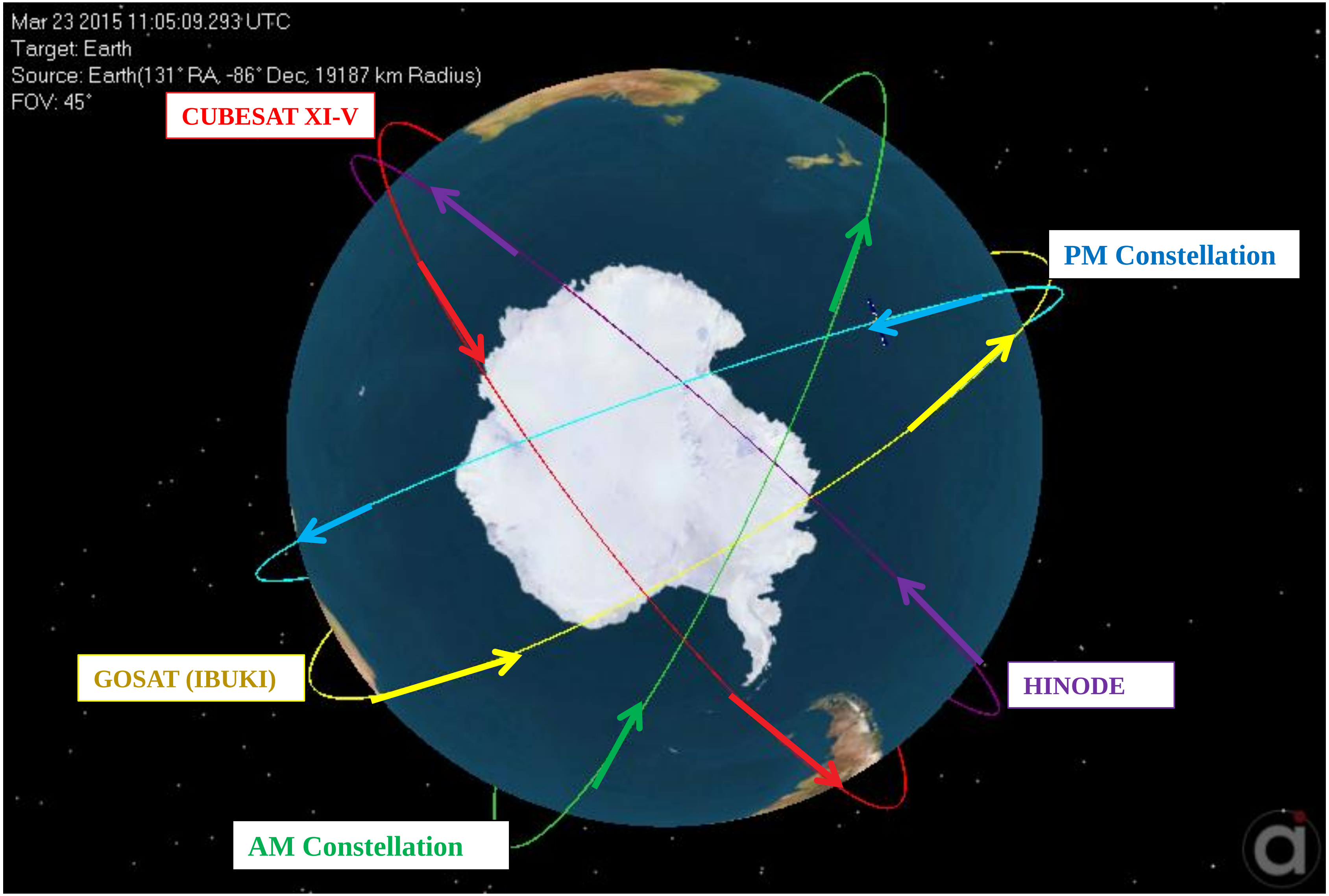
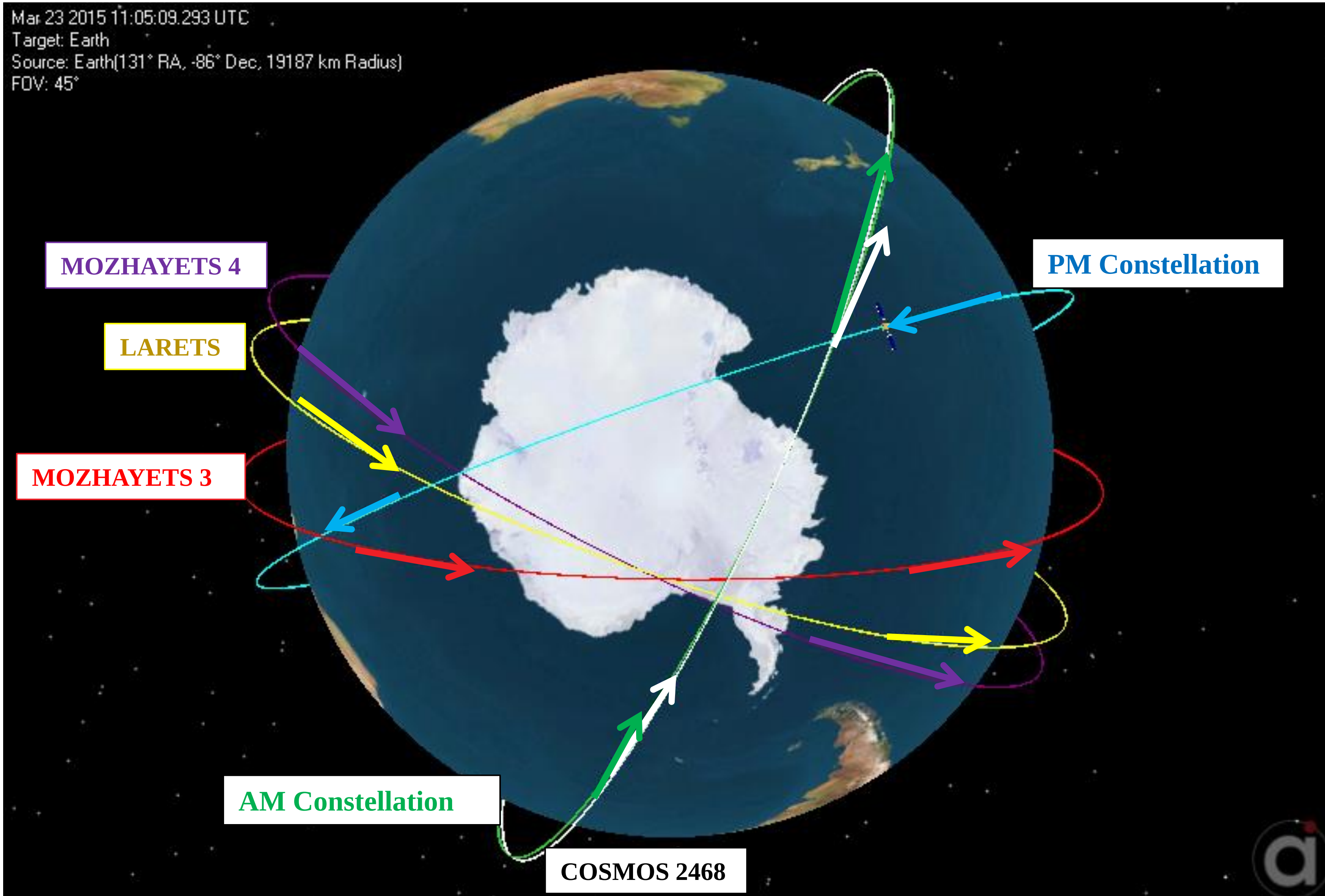
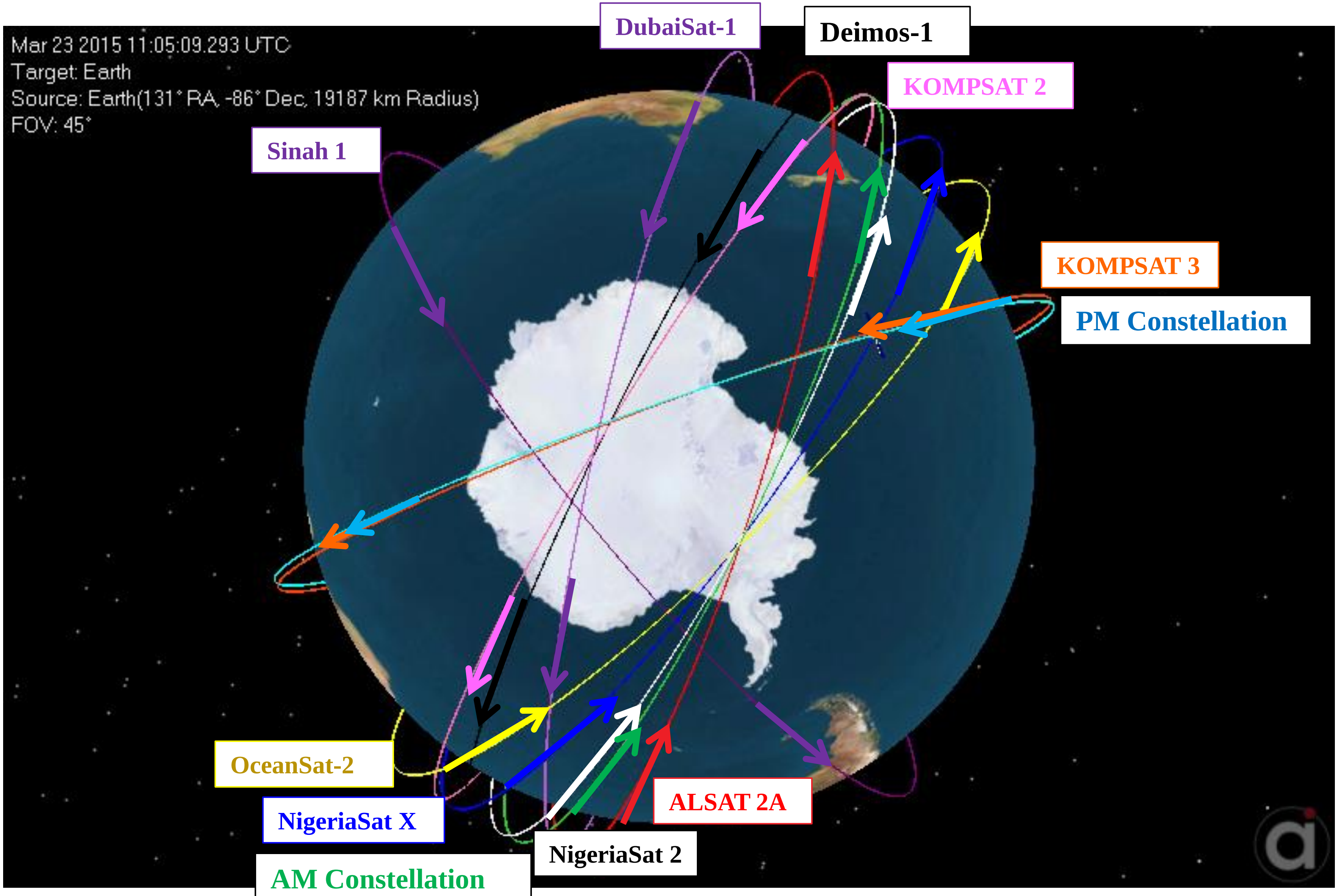
Japanese Satellite Orbits



Russian Satellite Orbits



Miscellaneous Satellite Orbits



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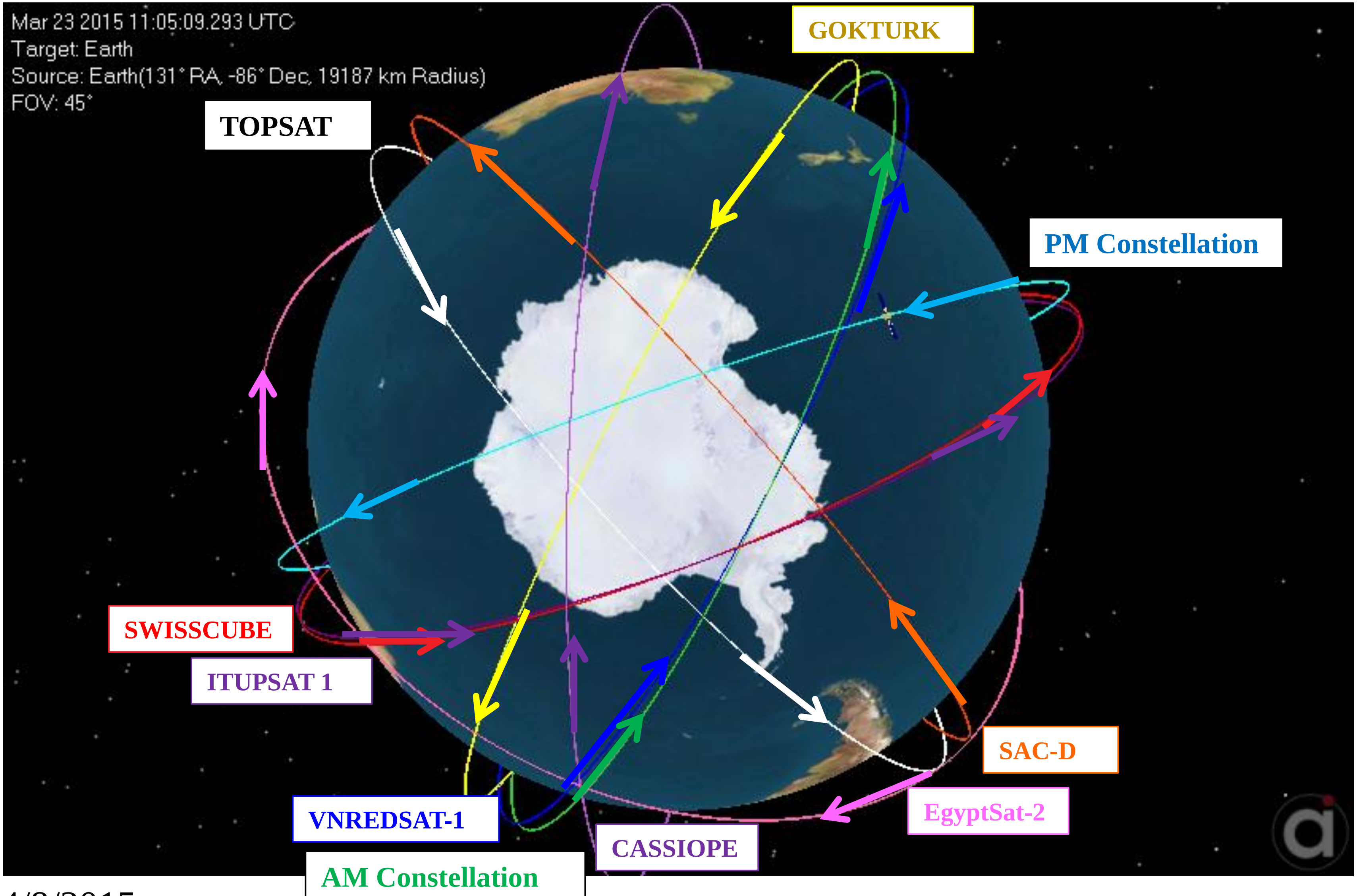
Miscellaneous Satellite Orbits



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Satellite Table of Properties

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
BEIJING 1 (28890)	China	2005	98.57	97.82	701	680
Chuangxin-3 (39209)	China	2013	98.10	98.03	671	665
SJ-11-01 (36088)	China	2009	98.66	98.25	702	687
SJ-11-02 (37765)	China	2011	98.59	98.26	701	682
SJ-11-03 (37730)	China	2011	98.61	98.11	698	686
SJ-11-05 (39202)	China	2013	98.63	98.18	702	684
SJ-11-06 (39624)	China	2014	98.66	98.21	704	686
SJ-11-07 (40261)	China	2014	98.61	98.10	702	683
SJ-11-08 (40286)	China	2014	98.59	98.22	701	682

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
PROBA-2 (36037)	ESA	2009	99.12	98.28	725	708
CRYOSAT 2 (36508)	ESA	2010	99.16	92.03	723	714
SENTINEL 1A (39634)	ESA	2014	98.68	98.18	697	695
PLEIADES 1 (38012)	France	2011	98.73	98.2	699	697
PLEIADES 1B (39019)	France	2012	98.73	98.17	699	697
SPOT 6 (38755)	France	2012	98.73	98.16	699	697
SPOT 7 (40053)	France	2014	98.73	98.17	699	697

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
RUBIN 4/SL-8 (27940)	Germany	2003	98.32	97.85	688	669
MOZ.5/SAFIR/ RUBIN 5/SL-8 (28898)	Germany	2005	98.64	97.84	707	680
BEESAT (35933)	Germany	2009	98.94	98.4	712	704
UWE-2 (35934)	Germany	2009	98.96	98.39	713	705
CUBESAT XI-V (28895)	Japan	2005	98.45	97.82	697	673
HINODE (SOLAR B) (29479)	Japan	2006	98.34	98.15	691	668
GOSAT (IBUKI) (33492)	Japan	2009	98.12	98.07	670	668

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
MOZHAYETS 3 (27560)	Russia	2002	98.83	98.09	732	673
MOZHAYETS 4 (27939)	Russia	2003	98.23	97.83	683	666
LARETS (27944)	Russia	2003	98.42	97.86	691	675
COSMOS 2468 (39177)	Russia	2013	99.21	98.23	732	710
IKONOS 2 (25919)	USA	1999	96.9	98.09	615	606
IRIDIUM 14 (25777)	USA	1999	100.4	86.4	779	776
C/NOFS (32765)	USA	2008	93.19	13	509	352
GEOEYE 1 (33331)	USA	2008	98.33	98.11	685	673

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
CINEMA 3 (39426)	USA	2012	98.07	97.73	742	591
DICE (37851)	USA	2011	96.38	101.72	726	444
E1P-2/HRBE (37855)	USA	2011	96.28	101.72	719	442
Orbcomm fm 103 (40091)	USA	2014	99.12	47.01	726	707
Orbcomm fm 104 (40090)	USA	2014	99.12	47.01	730	703
Orbcomm fm 109 (40086)	USA	2014	99.12	47.01	728	706
ALSAT 2A (36798)	Algeria	2010	98.19	98.01	673	671
SAC-D (37673)	Argentina	2011	97.8	98.01	655	652

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
CASSIOPE (39265)	Canada	2013	102.03	80.97	1387	322
DubaiSat-1 (35682)	Dubai	2009	98.09	97.91	675	659
EgyptSat-2 (39678)	Egypt	2014	99.05	51.62	714	713
SINAH 1 (28893)	Iran	2005	98.56	97.82	700	679
OCEANSAT 2 (35931)	India	2009	99.25	98.27	725	721
NIGERIASAT 2 (37789)	Nigeria	2011	98.51	98.12	696	679
NIGERIASAT X (37790)	Nigeria	2011	98.75	98.17	707	691

Note: This data should be used for informational purposes only

Satellite Table of Properties, Con't

Name and NORAD ID	Country of Origin	Launch Year	Period (min)	Inclination (deg)	Apogee (km)	Perigee (km)
KOMPSAT 2 (29268)	S. Korea	2006	98.51	98.17	701	674
KOMPSAT 3 (38338)	S. Korea	2012	98.5	98.12	695	679
SWISSCUBE (35932)	Switzerland	2009	98.95	98.4	714	704
ITUPSAT 1 (35935)	Turkey	2009	98.99	98.41	716	705
GOKTURK 2 (39030)	Turkey	2012	98.27	98.08	686	666
TOPSAT (28891)	UK	2005	98.57	97.82	702	678
Deimos-1 (35681)	Spain/UK	2009	97.87	98.04	659	655
VNREDSAT 1 (39160)	Vietnam	2013	98.44	98.15	685	683

Note: This data should be used for informational purposes only

Description of Constellation Envelope

- ***Completely inside of the constellation envelope:***

$$|sma_R - sma_A| + |sma_R * e_R - sma_A * e_{AMAX}| < Margin + Frozen\ Orbit\ Tolerance$$

- ***Completely outside of the constellation envelope:***

$$|sma_R - sma_A| - |sma_R * e_R - sma_A * e_{AMAX}| > Margin + Frozen\ Orbit\ Tolerance$$

- ***Traversing the constellation envelope meets neither of these criteria***
- ***See next slide for further details***

Description of Constellation Envelope

- ***sma_R = 7077.732 km (Mean SMA of 705-km reference orbit)***
- ***e_R = 0.00118 (Mean eccentricity of 705-km reference orbit)***
- ***Margin value = 2.5 km***
- ***Frozen Orbit Tolerance = 1.5 km (based on max eccentricity deviation of 0.0002)***
- ***sma_A = Mean SMA of foreign satellite orbit***
- ***e_{AMAX} = Max mean eccentricity of foreign satellite orbit***
  - The high 3-sigma value of the mean eccentricity was used in an attempt to account for the uncertainty of the TLE data

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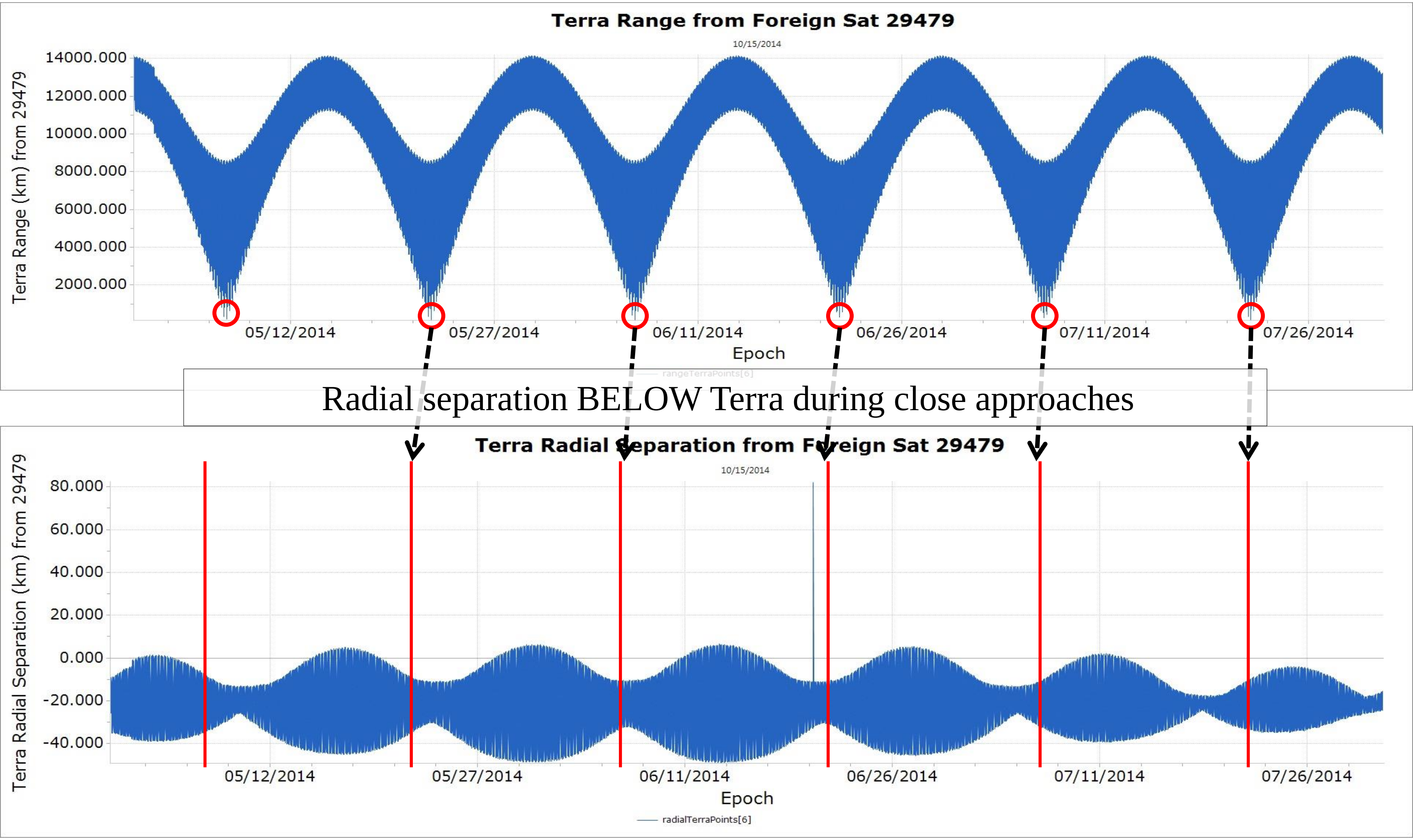
Terra Range/Radial Plots from HINODE (29479)



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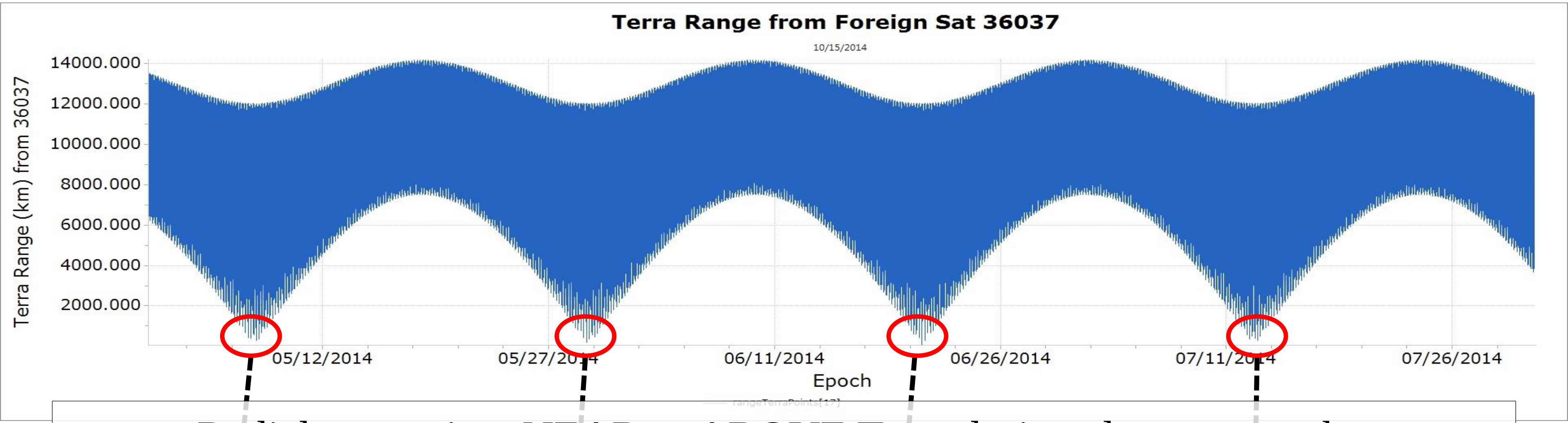
Terra Range/Radial Plots from PROBA 2 (36037)



Radial separation NEAR or ABOVE Terra during close approaches